

Far infrared and Far ultraviolet emissions of galaxies: luminosity functions and selection effects. Implications for the future NGST and ALMA observations

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Abstract. The FIR($60\ \mu\text{m}$) and UV ($0.2\ \mu\text{m}$) emissions of individual star forming galaxies are compared to the mean properties of the local Universe. Almost all the galaxies exhibit a FIR to UV flux ratio larger than the ratio of the FIR and UV luminosity densities. It is likely to be due to the contribution of low luminosity galaxies to the UV luminosity density: these galaxies are deficient in any survey.

As the galaxies become brighter in FIR their FIR to UV flux ratio increases: (around $0.2\ \mu\text{m}$) it implies an increase of 0.5 mag of extinction (around $0.2\ \mu\text{m}$) per decade of FIR ($60\ \mu\text{m}$) luminosity. This trend is extended and amplified in Ultra Luminous Infrared Galaxies observed at low and high redshift. The Lyman Break galaxies detected by their U dropout in the HDF seem to have less extreme properties more compatible with the trend found in the nearby star forming galaxies.

The detection limits of the NGST and of the future large millimeter array (ALMA) in terms of FIR to UV ratios are presented.

1. Introduction

At high redshift the emission observed in the visible corresponds to the ultraviolet range in the rest frame and the effects of the dust extinction can be dramatic. We need to know how to correct individual galaxies for extinction but also how the properties of these individual cases can be extrapolated to the entire population of the galaxies. The FIR to UV flux ratio of galaxies is now well recognized as a powerful indicator of the extinction (e.g. Buat & Xu 1996, Meurer et al. 1999). The basic idea of the present work is to compare the FIR ($60\ \mu\text{m}$) and UV($0.2\ \mu\text{m}$) emission of a sample of nearby galaxies for which selection biases are well known. The aim is to study how much these individual galaxies trace the mean properties of the local universe. The second step is to compare the properties of this sample to individual and more distant galaxies so far observed in FIR and UV (rest frame).

2. The FIR(IRAS)/UV(FOCA) ratio of nearby galaxies

2.1. The IRAS/FOCA sample of nearby galaxies

We have cross-correlated Far Infrared (IRAS) and Far Ultraviolet (FOCA, Donas et al. 1995) observations of galaxies to construct *a sample of FIR selected galaxies with a UV ($0.2\ \mu\text{m}$) observation.*

We have considered the 22 fields (~ 70 square degrees) observed in UV by the FOCA experiment and at present calibrated. We started from the IR detections for which much data are available and search for their UV counterparts. 83 spiral and irregular galaxies have been observed and securely measured both in UV and FIR.

2.2. The FIR to UV ratio in the IRAS/FOCA sample: Comparison with the luminosity densities

In Figure 1 is reported the ratio of fluxes at $60\ \mu\text{m}$ and $0.2\ \mu\text{m}$, $F_{60}/F_{0.2}$ as a function of the luminosity of the galaxies at $60\ \mu\text{m}$. ($F_\lambda = \lambda \cdot f_\lambda$ where f_λ is a flux per unit wavelength). There is a clear trend for a larger $F_{60}/F_{0.2}$ ratio for brighter galaxies at $60\ \mu\text{m}$. Using a moving median and a linear fit on the IRAS/FOCA data gives: $\log(F_{60}/F_{0.2}) = 0.31(\pm 0.07) \log L_{60} - 2.35(\pm 0.18)$. This fit is plotted as a solid line in Figure 1.

The FIR to UV flux ratio is a reliable tracer of the dust extinction (Buat & Xu 1996, Meurer et al. 1999, Witt & Gordon 1999). Using the calibration of Meurer et al. (1999) we find an extinction at $\sim 0.2\ \mu\text{m}$ increasing from 0.8 mag for $L_{60} = 10^8 L_\odot$ to 2.5 mag for $L_{60} = 10^{11} L_\odot$. The calibration of Buat & Xu (1996) gives extinctions ~ 0.4 mag lower (Buat et al. 1999).

Comparison with the local luminosity densities The $60\ \mu\text{m}$ local luminosity function and density at $z=0$ have been calculated by Saunders et al. (1990). The $0.2\ \mu\text{m}$ luminosity function and density have been derived by Treyer et al. (1998) at a mean $z=0.15$. From these studies we estimate the ratio of the local luminosity densities $\rho_{60}/\rho_{0.2}$ at $z=0$: $\rho_{60}/\rho_{0.2} = 0.9 \pm 0.4$. This value is reported in figure 1 as a dotted line. The ratio appears lower than almost all the ratios found for individual galaxies and *the study of individual galaxies of our sample does not lead to a reliable estimate of the mean FIR to UV ratio of the local Universe*

Table 1. Contribution of the galaxies to the $0.2\ \mu\text{m}$ and $60\ \mu\text{m}$ luminosity function and to the $0.2\ \mu\text{m}$ and $60\ \mu\text{m}$ luminosity density in the local Universe per decade of luminosity. The luminosity function is truncated at $L = 10^7 L_\odot$ ($h = H_0/100$)

$\log(L_{UV})$ solar unit	galaxies from the lum.func	contribution to the lum.dens.	galaxies IRAS/FOCA sample
7-8 h^{-2}	77.3%	17 %	10%
8-9 h^{-2}	19.3%	36%	35%
9-10 h^{-2}	3.2 %	36%	55%
10-11 h^{-2}	0.2 %	11%	0%
$\log(L_{FIR})$ solar unit	galaxies from the lum.func	contribution to the lum.dens.	galaxies IRAS/FOCA sample
7-8 h^{-2}	45.4 %	2%	3%
8-9 h^{-2}	35.6 %	15%	17%
9-10 h^{-2}	16.2 %	40%	57%
10-11 h^{-2}	2.7 %	34%	23%
11-12 h^{-2}	0.1 %	8%	0%

Comparison with the local luminosity functions An explanation for the discrepancy between the $F_{60}/F_{0.2}$ ratio of individual galaxies and the ratio of the local luminosity densities is that it is not the same galaxies which form the bulk of the UV emission on one hand and the FIR emission on the other hand. This seems confirmed by the very different shapes of the luminosity functions (Figure 2). From Table 1 it is clear that our individual galaxies do not truly sample the luminosity functions. The bright end of both luminosity functions is not represented in the IRAS/FOCA sample because of the scarcity of these objects and the small statistics. The steepness of the faint end slope of the UV luminosity function implies a large number of faint galaxies which largely contribute to UV luminosity density: these galaxies are deficient in any survey and in particular in our IRAS/FOCA sample. The FIR luminosity function is better sampled in the sense that the deficiency of low luminosity galaxies has less implications than in UV. This is due to the flatness of the FIR luminosity function at low luminosities.

3. Comparison with the FIR bright galaxies and the U-dropout galaxies of the Hubble Deep Field

FIR bright Galaxies We have also reported in Figure 1 the data available for nearby (Trentham et al. 1999) and high redshift (Hughes et al. 1998) Ultra Luminous Infrared Galaxies (ULIGs) as well as the galaxies detected by ISOCAM in a CFRS field (Flores et al. 1998). All these FIR bright objects exhibit a larger F_{60}/F_{UV} ratio than suggested by the extrapolation of the linear regression (solid line) found for the IRAS/FOCA sample. The nearby and high z ULIGs have very large extinctions (from 7 to 11 mag) in UV as measured from the FIR to UV flux ratio (Buat et al. 1999). The ISOCAM/CFRS galaxies exhibit a more moderate UV extinction (2-5.5 mag) with a mean at 3.3 mag. As a comparison the extinction of Messier 82 at $0.2 \mu\text{m}$ estimated in the same way is 5.4 mag (Buat & Burgarella 1998).

U-dropout, Lyman break galaxies Meurer et al. (1999) have studied the U-dropout galaxies detected in the HDF to their local starburst templates in terms of dust extinction and UV luminosity distribution. In order to compare these galaxies to our IRAS/FOCA sample we have estimated their F_{60}/F_{UV} ratio and their luminosity at $60 \mu\text{m}$.

The $60\mu\text{m}$ luminosity is estimated from the Star Formation Rates (SFRs) of the galaxies: from the figure 6 of Meurer et al. we deduce a range in SFR 2-300 M_{\odot}/yr . The total infrared luminosity L_{IR} is deduced from the relation $SFR = 1.71 \cdot 10^{-10} L_{IR}(L_{\odot})$ (Kennicutt 1998). Adopting $L_{IR}/L_{60} \simeq 1.4$ (Buat & Burgarella, 1998; Meurer et al. 1999), we obtain L_{60} in the range $8.5 \cdot 10^9 - 1.3 \cdot 10^{12} L_{\odot}$.

The F_{60}/F_{UV} ratio is estimated from the extinction deduced by Meurer et al. with the shape of the UV continuum: the range for $A(0.16\mu\text{m})$ is 0.1-3 mag which translates to a F_{60}/F_{UV} ratio comprised between 1.4 and -0.6 in log units (Buat et al. 1999, their figure 1).

The location of the U-dropout galaxies in Figure 1 is within the dashed squared area. *The Lyman Break galaxies detected by their U dropout in the HDF seem to*

have less extreme properties than ULIGs more compatible with the trend found in the nearby star forming galaxies.

4. The future NGST and ALMA observations

The **New Generation Space Telescope(NGST)** coupled with the **Atacama Large Millimeter Array (ALMA)** will allow to obtain the FIR and UV rest-frame emissions of galaxies in the early Universe. We have tentatively estimated the limiting luminosities reachable by these instruments at both wavelengths. The results are gathered in Table 2. We have reported these limits in figures 1 and 2 for the redshifts ~ 5 and ~ 20 .

The UV luminosity function is well sampled by the NGST up to $z=20$ whereas only FIR bright galaxies will be detected by ALMA at $z>5$. In terms of FIR to UV ratios, at $z=5$ all the range of F_{60}/F_{UV} sampled by the objects reported in figure 1 will be reachable, at $z=20$ galaxies similar to ULIGs will be only marginally detected in UV.

Table 2. Detection limits of NGST and ALMA. The calculations are made for the four ALMA bands at 230, 350, 650 and 850 GHz which correspond to a rest frame emission at 60 μm for $z=20$, 13.3, 6.7 and 4.8. The corresponding NGST wavelengths corresponding to 0.2 μm rest frame are 4.2, 2.9, 1.5 and 1.2 μm . We assume point source distributions, a signal to noise ratio of 3 and 1 hour exposure.

redshift	$L_{\text{lim}}(0.2\mu\text{m})(\text{solar units})$	$L_{\text{lim}}(60\mu\text{m}) (\text{solar units})$
4.8	$6.2 \cdot 10^7 h^{-2}$	$2.7 \cdot 10^{10} h^{-2}$
6.7	$10 \cdot 10^7 h^{-2}$	$2.5 \cdot 10^{10} h^{-2}$
13.3	$23.8 \cdot 10^7 h^{-2}$	$1.25 \cdot 10^{10} h^{-2}$
20	$69 \cdot 10^7 h^{-2}$	$1.33 \cdot 10^{10} h^{-2}$

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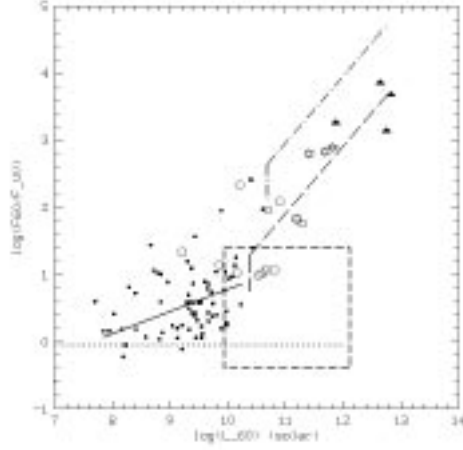


Figure 1. The ratio of the emission at 60 and 0.2 μm as a function of the luminosity at 60 μm . The IRAS/FOCA sample is plotted as dots, the linear fit is represented by the solid line. The ratio of the local luminosity densities $\rho_{60}/\rho_{0.2}$ is reported as a dotted horizontal line. FIR bright and U-dropout galaxies are overplotted: CFRS/ISOCAM galaxies as empty circles, nearby ULIRGs as stars and high z ULIRG as filled triangles. **ALMA/NGST** detection limits are represented as a dash-dotted line ($z=5$) and a long dashed line ($z=20$)

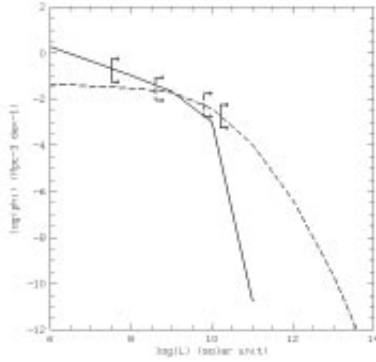


Figure 2. The luminosity functions at 0.2 μm (solid curve) and 60 μm (dashed curve). The detection limits of the NGST and ALMA for $z = 5$ (solid arrows) and $z = 20$ (dotted arrows) are reported on both curves.